Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION	Unclassified
1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY	
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
3. DISTRIBUTION / AVAILABILITY OF REPORT	Approved for public release: distribution unlimited
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	
5. MONITORING ORGANIZATION REPORT NUMBER(S)	
6a. NAME OF PERFORMING ORGANIZATION	University of California, Los Angeles
6b. OFFICE SYMBOL (If applicable)	
7a. NAME OF MONITORING ORGANIZATION	Office of Naval Research
6c. ADDRESS (City, State, and ZIP Code)	6532 Boelter Hall, Dept. Mat. Sci. & Engr. Los Angeles, CA 90024-1595
7b. ADDRESS (City, State, and ZIP Code)	Physics Division Code 1112 Arlington, VA 22217-5000
8a. NAME OF FUNDING / SPONSORING ORGANIZATION	
8b. OFFICE SYMBOL (If applicable)	
9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	N00014-81-K0011
8c. ADDRESS (City, State, and ZIP Code)	

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
61153N11		4126700	

11. TITLE (Include Security Classification)

Navy Vehecles: Acoustic Emission Related to Nondestructive Testing

12. PERSONAL AUTHOR(S)
Ono, Kanji

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
FINAL	FROM 1980 TO 1987	19880412	15

16 SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

See the next page

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	Unclassified

22a NAME OF RESPONSIBLE INDIVIDUAL	22b TELEPHONE (Include Area Code)	22c OFFICE SYMBOL
L. E. Hargrove	(202) 696-4221	ONR Code 1112

NAVY VEHICLES: ACOUSTIC EMISSION RELATED TO NONDESTRUCTIVE TESTING

ABSTRACT

This investigation was aimed at studying acoustic emission for applications to residual stress measurements and for the evaluation of structural integrity of engineering structures. Effects of microstructure, composition and prior cold working on magnetomechanical acoustic emission (MAE) have been studied. Magnetization behavior, magnetostriction and Barkhausen noise are affected by stress as well as other parameters. These responses have been measured simultaneously in order to identify the stress level uniquely. Combinations of advanced signal analysis methods and MAE measurements have been studied to identify the optimum parameters for applications. This work has established mechanisms of MAE signal generation, effects of various parameters that influence the MAE behavior of materials and signal processing techniques that allow materials characterization via MAE. Included are neutron irradiated reactor vessel steels, large size steel plates as well as single crystals of various ferromagnetic metals and alloys.

In the second part of this study, acoustic emission from materials undergoing plastic deformation and fracture have been examined in an attempt to improve detection capability of the impending structural failure. Acoustic emission characteristics of reactor vessel steels, advanced aluminum alloys and metal and ceramic matrix composite materials have been evaluated in detail. Digital signal analysis techniques have been used to investigate further the different types of acoustic emission signals from various sources. This study has clarified acoustic emission signals produced by a number of different mechanisms during plastic deformation and fracture of these materials. These include dislocation related mechanisms, inclusion decohesion and fracture, crack propagation, fiber fracture, delamination and splitting of fibrous composites, among others.

I. INTRODUCTION

Much progress has been made in recent years in understanding the nature of acoustic emission (AE), and in practical application of AE methods to nondestructive evaluation of components and structures. Clearly, AE signals are related to microscopic sources producing them and their suitable analyses should yield information about the sources. The information, in turn, can provide the basis for an improved nondestructive testing (NDT) method for the prediction of structural failure and/or for the detection of dangerous flaws.

The major goals of this investigation have been (1) research and development of a new method of residual stress measurement and (2) characterization of AE signals and correlation of the characteristics with physical causes. We have contributed significant knowledge in the understanding of AE due to plastic flow, that of AE in structural steels and that of the basic causes of MAE. Other areas in the applications of MAE and fracture related AE in welds and composite materials also received attention in our research efforts.

II. SUMMARY OF RESULTS

Residual Stress Measurement and Materials Characterization by MAE Method

This investigation was aimed at studying acoustic emission for applications to residual stress measurements and materials characterization. Stress waves arising from magnetostriction of ferromagnetic materials are called magnetomechanical AE. The basic cause involves magnetostriction during magnetic domain wall movement. Effects of microstructure, composition and prior cold working on magnetomechanical acoustic emission (MAE) have been studied. Magnetization behavior, magnetostriction and Barkhausen noise are affected by stress as well as other parameters. These responses were measured simultaneously in order to identify the stress level uniquely. Combinations of advanced signal analysis methods and MAE measurements provide the most promising NDE methods, and have been studied to identify the optimum parameters for applications.

We have generated the basic knowledge on MAE. From simultaneous measurements of MAE, magnetization (B-H) curve, magnetostriction and Barkhausen noise, much information has been accumulated and the interrelationships of various factors have been clarified. Our study has employed Fe, Ni, Fe-Ni alloys and Fe-Si alloys and test temperature, stress, microstructures and amount of cold work have also been varied. Relying on the results of the basic MAE study, we have continued to explore several different schemes for practical implementation of MAE for residual stress applications. The most promising one relies on the intensity ratio of MAE at different field or frequency ranges. A number of other combinational approaches are also evaluated. By utilizing all the available data on MAE and magnetization for separate identification of residual stress, prior cold work, chemical composition and heat treatment can be made for components of constant geometries.

During the period of this contract, M. Man Kwan, O.Y. Kwon, M. Ohtsu and M. Shibata worked in the area of MAE. Both Kwan and Kwon received Ph. D. based on the work, the latter in March 1988. Published papers are listed at the end of this report and Nos. 1 to 10 are concerned with the topic of MAE. In this area, 19 presentations were made (see the listing that follows). One more is planned for April 1988 (No. 20).

Since the work of Dr. Kwon just completed has not been included in the listing above, the abstract of his thesis will be included as an appendix to this report. Two chapters of the thesis are on MAE and two or more papers will be prepared in the near future. In this work, he obtained MAE and Barkhausen noise (BN) data from large steel samples up to 6 feet long. These tests evaluated effects of sample size and resonant vibration on MAE data. It is shown that rapid decrease of MAE intensity at low stresses in small samples is in fact due to efficient acoustic coupling provided by the applied stresses. In large samples, the slope of MAE intensity vs. stress plots becomes small, but nearly constant. Next, he used pattern recognition analysis including the data of the large samples and a new set of steel samples. Five envelopes were determined for each sample and stored in a microcomputer. These waveform data were then processed using a pattern recognition analysis software and classified according to heat treatment. Nearly perfect classification was achieved. This indicates that we can detect differences in steel heat treatment via MAE and BN signals. The envelope based pattern classification system works well for MAE data for both stress and microstructural characterization. Dr. Kwon extended the MAE characterization and pattern recognition analysis work to neutron irradiated samples. The samples were of nuclear pressure vessel steels and model alloys, irradiated up to $10^{19} n/cm^2$. Four different irradiation conditions were evaluated along with control samples. The irradiation was performed at University of Virginia by a group from University of California, Santa Barbara. The results showed that neutron irradiation produces substantial changes in MAE waveforms and intensity. As much as 30 % changes were observed. Since no other method is capable of detecting irradiation effects with this large sensitivities or with nondestructive means, this should be developed further to make MAE a monitoring method for irradiation embrittlement.

Structural Monitoring by Acoustic Emission

In the second part of this project, acoustic emission from materials undergoing plastic deformation and fracture has been examined in an attempt to improve detection capability of the impending structural failure. We have established new acoustic emission techniques and applied them in studying the acoustic emission behavior of advanced aluminum alloys, reactor vessel steels and composite materials. Digital signal analysis techniques are used to investigate further the different types of acoustic emission signals from various sources. A major emphasis has been placed on the fracture related AE in high strength aluminum-lithium alloys and fiber-reinforced advanced composites including metal matrix (Al-SiC) and resin matrix (graphite-epoxy) materials.

In this part of the project, we have attempted to establish the basic understanding of AE from structural materials in order to provide a firm foundation on which one can utilizes AE as a tool for NDE applications. It is important to identify the origins of different types of acoustic emission. We have studied AE associated with plastic deformation and fracture of structural alloys. In particular, our studies have discovered the dominant role of emissions arising from non-metallic inclusions in steels. In aluminun-lithium alloys, we have found that various precipitates control the slip behavior, which in turn affects acoustic emission characteristics. This work is being continued by Gerry Zamiski as a non-funded Ph. D. thesis research and will be completed in 1988.

Eighteen papers have been published in the area of AE behavior of structural metallic alloys. These are listed as Ref. 11 to 28. AE due to plastic deformation of homogeneous materials was discussed in Ref. 11, 12, 16, 18, 20, 21, and 27. Temperature dependent deformation, microstructural effects and thermal treatment effects have been clarified. AE arising from non-metallic inclusions of steels has also been analyzed. The studies resulted in Refs. 13 - 15, 19, 22 - 24, 26 as well as 28. We have established that main source of AE in structural steels is the decohesion of nonmetallic inclusions, such as MnS. We started to study a new structural Al alloy with Li and the initial report was given as Ref. 27. It showed that coherent precipitates produce quite different AE behavior and additional studies are being conducted as indicated above. Another area of interest from applications approach is the use of pattern recognition analysis. This method can provide real-time discrimination of various detected AE signals. Ref. 25 reports an application of a digital technique to fracture AE analysis.

Another thrust area has been AE from composite materials. Advanced fiber reinforced composites with metal and resin matrices have been used in increasing numbers in a variety of naval aircrafts and weapons systems. Yet, NDE techniques leave much to be desired. AE has been used to locate flaws in numerous missile motorcases. However, the nature of emission processes has not been clarified in many instances. This is especially true in metal matrix composites (MMC), but resin matrix composites are not well understood either.

We have studied MMC plates of SiC whiskers and SiC particulate reinforced Al matrix composites. These composite samples were investigated for their AE behavior during tensile and fracture tests as a function of heat treatment. In conjunction with fractographic studies, it was concluded that fracture in whisker reinforced composites initiates and propagates in the matrix and does not involve whisker fracture. In the particulate reinforced MMC's, interfacial separation was found to be predominant. These studies were reported in Refs. 32 and 33.

The second composite material studied was unidirectional carbon fiber reinforced epoxy. The samples were fabricated in-house using prepregs and included several types of artificial flaws. The flaws promote delamination, splitting and fiber fracture. By evaluating fracture morphologies and AE behavior, AE characteristics of specific types of AE generaing mechanisms have been clarified. In addition, pattern recognition analysis techniques were applied to separate AE signals of different origins. Although the analysis procedures are complex at present, different types of AE signals can be successfully classified. These

investigations were reported in Refs. 30, 31, 34 - 36.

Presentations on these topics are listed in the reference section. These include a talk on glass-epoxy composites, residual stresses and general acoustic emission. A list of students and scholars who received financial support is given in the Reference section. Degrees received by some of them are also listed.

III. REFERENCES

Publications

1. K. Ono and M. Shibata, "Magnetomechanical AE for Residual Stress and Prior Strain and Prior Strain Determination," *Advances in Acoustic Emission,* edited by H.L. Dunegan and W.F. Hartman, Dunhart, Knoxville, 1981, pp. 154-174.

2. K. Ono, M. Shibata and M. Man-Kwan, "Determination of Residual of Residual Stress by MAE," *Residual Stress for Designers and Metallurgists,* edited by L.J. Vande Walle, ASM, Metals Park, Ohio, 1981, pp. 223-243.

3. M. Shibata and K. Ono, "MAE - New Method for Nondestructive Stress Measurement," *NDT International,* vol. 5 227-234, 1981.

4. M. Shibata, M.M. Kwan, K. Ono, "MAE in Fe-Ni Alloys," *Proc. 3rd AE Conf.,* Japan Soc. Nondestructive Inspection, Tokyo, Japan, 1981, pp. 225-230.

5. M. Man Kwan, K. Ono and M. Shibata, "Magnetonechanical Acoustic Emission - Temperature Effects", *Progress in Acoustic Emission, II,* eds. M. Onoe et al, Japan Soc. NDI, Tokyo, 1984, pp. 97-104.

6. M. Ohtsu and K. Ono, "Pattern Recognition Analysis of Magneto- Mechanical Acoustic Emission," J. Acoustic Emission, 3(2):69-80, 1984.

7. M. Man Kwan, K. Ono and M. Shibata, "Magnetonechanical Acoustic Emission of Ferromagnetic Materials at Low Magnetization Levels (Type I Behavior)", J. Acoustic Emission, 3(3):144-158, 1984.

8. M. Man Kwan, K. Ono and M. Shibata, "Magnetonechanical Acoustic Emission of Ferromagnetic Materials at High Magnetization Levels (Type II Behavior)", J. Acoustic Emission, 3(4):190-203, 1984.

9. K. Ono, "Residual Stress Determination using Magnetomechanical Acoustic Emission", in *Advances in Surface Treatments,* ed. by A. Niku-Lari, Pergamon Press, Oxford (in press).

10. K. Ono, "Magnetomechanical Acoustic Emission - A Review", in *Progress in Acoustic Emission, III,* eds. M. Onoe et al., Japan Soc. NDI, Tokyo, 1986, pp. 200-211.

11. S.-Y.S. Hsu and K. Ono, "AE of Plastic Flow - I. Metals," *The Fifth International Symposium,* Japanese Society NDT, Tokyo, 1980, pp. 283-293.

12. S.-Y.S. Hsu and K. Ono, "AE of Plastic Flow - II. Alloys," The Fifth International Symposium, Japanese Society NDT, Tokyo, 1980, pp. 294-303.

13. K. Okajima and K. Ono, "Temperature Dependence of Anisotropic AE Behavior of A533B Steel," The Fifth International Symposium, Japanese Society NDT, Tokyo, 1980, pp. 270-281.

14. M. Yamamoto, C. Ouchi and K. Ono, "The Directional Properties of HSLA Steels During AE and Fracture Testing," The Fifth International Symposium, Japanese Society NDT, Tokyo, 1980, pp. 221-235.

15. K. Ono and M. Yamamoto, "Anisotropic Mechanical and Acoustic Emission Behavior of A533B Steels," *Mat. Sci. and Engr.,* 47, 1981, 247-263.

16. R. Landy and K. Ono, "Acoustic Emission Behavior of a Low Alloy Steel," *Journal of Acoustic Emission, 1* 7-19, 1982.

17. I. Roman and K. Ono, "Model for Fracture Toughness Alternation due to Cyclic Loading," *International Journal of Fracture, 19* 67-80, 1982.

18. S-Y. S. Hsu and K. Ono, "Acoustic Emission Behavior of Nickel during Tensile Deformation," J. Acoustic Emission, 1:183-190, 1982.

19. H. B. Teoh, I. Roman, K. Ono, *Progress in Acoustic Emission,* M. Onoe et al., (eds) Jap. Soc. NDT, Tokyo, 1982, pp. 21-30.

20. S-Y. S. Hsu and K. Ono, Progress in Acoustic Emission, M. Onoe et al., (eds) Jap. Soc. NDT, Tokyo, 1982, pp. 235-243.

21. S.-Y.S. Hsu and Kanji Ono, "Effects of Solute Distribution on Acoustic Emission Behavior of Solid Solution Alloys," J. of Acoustic Emission, 2(3):169-178, 1983.

22. I. Roman, H.B. Teoh, and K. Ono, "Thermal Restoration of Burst Emissions in A533B Steel," J. of Acoustic Emission, 3(1):19-26, 1984.

23. H.B. Teoh, K. Ono and I. Roman, "Fracture Induced Acoustic Emission of A533B Steel - Effects of Test Temperature and Fracture Mechanisms," *Progress in Acoustic Emission, II,* eds. M. Onoe et al, Japan Soc. NDI, Tokyo, 1984, pp. 105-113.

24. H.B. Teoh, K. Ono, E. Kobayashi and I. Roman, "Effects of Interfacial Segregation on Acoustic Emission Behavior of A533B Steel," J. Acoustic Emission, 3(3):130-143, 1984.

25. M. Ohtsu and K. Ono, "Discrimination of Fracture Mechanisms via Pattern

Recognition Analysis of AE Signals during Fracture Testing", J. Acoustic Emission, 4, S316, 1985.

26. I. Roman, K. Ono and O.Y. Kwon, "Burst Emission Behavior of Structural Steels," J. Acoustic Emission, 4, S106 1985.

27. I. Roman and K. Ono, "AE Behavior of Advanced Aluminum Alloy," J. Acoustic Emission, 4, S111, 1985.

28. H.B. Teoh and K. Ono, "Fracture Mechanisms and AE in A533B Steel," J. Acoustic Emission, 6(1), 1-12, 1987.

29. K. Ono and R. de Spain, "Characterization of Carbon Fiber Composites using Acousto-Ultrasonic Techniques," *SPI CARP International Symposium - 1983,* Proceedings of the Fisrt International Symposium on AE from Reinforced Plastics, Soc. Plastics Ind., New York, 1983, Session 6, pp. 1-5.

30. I. Roman and K. Ono, "Acoustic Emission Characterization of Fracture Mechanisms in Woven Roving Glass-Epoxy Composites," *Progress in Acoustic Emission, II,* eds. M. Onoe et al, Japan Soc. NDI, Tokyo, 1984, pp. 496-503.

31. K. Ono, "Acoustic Emission Behavior of Flawed Unidirectional Carbon Fiber-Epoxy Composites", Proc. 2nd International Symposium on AE from Reinforced Composites, Montreal, July 1986, Soc. Plastics Industry, pp. 22-28, 1986.

32. C. Johnson, K. Ono and D. Chellman, "Acoustic Emission Behavior of Whisker Reinforced Aluminum during Fracture," J. Acoustic Emission, 4, S263 1985.

33. C. Johnson, K. Ono and D. Chellman, "A Study of Mechanical Behavior of Metal Matrix Composites Using Acoustic Emission", *Composites '86, Recent Advances in Japan and the U.S.,* Proc. of the Third Japan-U.S. Conference on Composie Materials, June 1986, Tokyo, Japan, 647-654.

34. M. Ohtsu and K. Ono, "Pattern Recognition Analysis of Acoustic Emission from Unidirectional Carbon Fiber-Epoxy Composites by the Use of Autoregressive Modeling," J. Acoustic Emission, 6(1), 61-72, 1987.

35. K. Ono, M. Ohtsu and S. Jensen, "Identification of Damages in Unidirectional Carbon Fiber-Epoxy Composites with Artificial Flaws via Acoustic Emission Techniques", Proc. ICCM-6, Vol. 1, Elsevier, London, 1987, pp. 1-471-480.

36. K. Ono, "Acoustic Emission Behavior of Flawed Unidirectional Carbon Fiber-Epoxy Composites", J. Reinforced Plastics and Composites, 7(1), 90-105, 1988.

Presentations

1. Ono, K. "Current Topics on AE-MAE in Particular," Japanese Committee on Acoustic Emission Meeting, Tokyo, Japan, November 1980.

2. Ono, K. "MAE," Kawasaki Steel Corporation, Chiba, Japan, November 1980. (Invited Seminar)

3. Ono, K. "AE Test Variables and MAE" AE Workshop, ASNT, San Diego, CA, November 1981.

4. Ono, K., Shibata, M., and Man-Kwan, M. "Determination of Residual Stress by MAE," presented at WESTEC 1981, Los Angeles, CA, March, 1981.

5. Shibata, M., Man-Kwan, M., and Ono, K., "MAE in Fe-Ni Alloys," presented at the 23rd Meeting of AEWG, Toronto, December, 1981.

6. Man-Kwan, M., Shibata, M., and Ono, K. "MAE of Fe-Ni Alloys," presented at the 10th Meeting of EWGAE, Zurich, Switzerland, October, 1981.

7. Man-Kwan, M., Shibata, M., and Ono, K. "MAE of Fe-Ni Alloys," presented at the 3rd Conference on Acoustic Emission, Tokyo, October, 1981.

8. Shibata, M., Man-Kwan, M., Ono, K. "MAE," Fall meeting of ASNT, Atlanta, Georgia, October, 1981.

9. Man-Kwan, M., Shibata, M., Ono, K. "MAE of Fe-Ni Alloys," 22nd AEWG Meeting, Boulder, CO, March 1981.

10. Shibata, M., and Ono, K. "Effects of Tempering on MAE Responses of Several Steels," presented at the 24th Meeting of Acoustic Emission Working Group, September 5-8, 1982, Knoxville, TN.

11. Ono, K., "Magnetomechanical AE," IRSID, 21 April, 1983, St. Germain, FRANCE.

12. Ono, K., (invited) "Application of MAE in the Nondestructive Measurement of Stress in Iron and Steel," Texas A&M University, College Station, TX, 22 June 1984.

13. Ono, K., "Magnetic and Ultrasonic Techniques and Evaluation," Residual stress Measurement and Analysis, Engineering Short Course, Union College, Schenectady, New York, 9-11 July 1984. (Invited)

14. Man-Kwan, M., Shibata, M., and Ono, K. "Magnetomechanical Acoustic Emission (MAE) of Ferromagnetic Materials at Low Magnetization Levels (Type 1 Behavior)," presented at the 26th AEWG Meeting, Reno, Nevada, 2-5 April 1984.

15. Man-Kwan, M., Shibata, M., and Ono, K. "Magnetomechanical Acoustic Emission-

Temperature Effects," presented at the 13th EWGAE Meeting, AERE, Harwell, England, 10-12 October 1984; and the 7th International AE Symposium, Zao, Japan, 23-26 October 1984.

16. Ono, K., "Ultrasonic Techniques and Evaluation," Residual Stress Measurement and Analysis, Engineering Short Course, Residual Stress Analysis, Society of Experimental Mechanics, Orlando, FL, 13-15 January 1985. (Invited Lecturer)

17. Ono, K., "Ultrasonic Stress Measurement Methods," Residual stress Analysis Workshop, Society of Experimental Mechanics, Los Angeles, CA, 25-27 March 1985. (Invited Lecturer).

18. Ono, K. "Magnetic Techniques and Evaluation for Residual Stress Measurement and Analysis", Engineering Short Course, Residual Stress Analysis, Society of Experimental Mechanics, Orlando, FL, 13-15 January 1986. (Invited Lecturer)

19. Ono, K., "Magnetomechanical Acoustic Emission - A Review," presented at the 8th International AE Symposium, Tokyo, October, 1986. (Invited Paper)

20. Roman, I., Ono, K., Teoh, H.B. "The Effect of Heat Treatment on Burst-Type AE of Previously Loaded A533B Steels," presented at the 10th EWGAE Meeting, Zurich, October, 1981.

21. Roman, I., Ono, K., Teoh, H.B. "The Effect of Heat Treatment on Burst-Type AE of Previously Loaded A533B Steels," presented at the 23rd AEWG Meeting, Toronto, Canada, December, 1981.

22. Hsu, S.-Y.S., Ono, K. "Acoustic Emission Behavior of Substitutional Alloys," 22nd AEWG Meeting, Boulder, CO, March 1981.

23. Okajima, K., Ono, K. "Temperature Dependence of Anisotropic Acoustic Emission Behavior of A533 Steel," 22nd AEWG Meeting, Boulder, CO, March 1981.

24. Hsu, S.-Y.S., and Ono, K. "Acoustic Emission Behavior of Nickel during Tensile Deformation," presented at the 6th International Acoustic Emission Symposium, October, 1982.

25. Teoh, H.B., Ono, K., and Roman, I. "Effect of Heat Treatment on Burst Type Acoustic Emission of A533B Steel," presented at the 24th Meeting of Acoustic Emission Working Group, September 5-8, 1982, Knoxville, TN.

26. Teoh, H.B., Ono, K., and Roman, I. "Effect of Heat-Treatment on Burst-Type Acoustic Emission of A533B Steel," presented at the 6th International AE Symposium, 31 October - 3 November 1982, Susono-city, Japan, Distributed as ONR-TR-82-01.

27. Ono, K. "AE from High-Temperature Deformation," Gordon Conference on Physical Metalurgy, Plymouth, New Hampshire, 20-25 June 1983. (Invited)

28. Ono, K., Imai, K. "Effects of Heat Treatment on AE and MAE Responses of AISI 4140 and 4340 Steels," presented at the 25th Meeting of AEWG, Princeton, New Jersey, 26-29 June, 1983.

29. Ono, K. "AE Characteristics of A533B Steels during Deformation and Fracture," presented at DoE AE/Fracture Workshop. University of Denver, Denver, CO, 14-15 March 1984. (Invited)

30. Ono, K., and Imai, K. "AE and MAE of 4140 and 4340 Steels," presented at the 26th AEWG Meeting, Reno, Nevada, 2-5 April 1984.

31. Ono, K., "Acoustic Emission," Brookhaven National Laboratories, Upton, New York, 13 July 1984. (Invited)

32. Ono, K. "Acoustic Emission," University of Southern California, 10 February 1984. (Invited)

33. Roman, Itzhak, Teoh, H.B., and Ono, K. "Effects of Pre-Loading and Heat Treatment on Burst-Type Acoustic Emission of A533B Steel," presented at the 26th AEWG Meeting, Reno, Nevada, 2-5 April 1984.

34. Teoh, H.B., Roman, I., and Ono, K. "Fracture Induced AE of A533B Steels - Effects of Test Temperature and Fracture Mechanisms," presented at the 13th Meeting of European Working Group on AE, at AERE Harwell, 10-12 October 1984, and at the 7th International AE Symposium, Zao, Japan, 23-26 October 1984.

35. Teoh, H.B., Ono, K. "Fracture Mechanisms and AE in A533B Steel," presented at the 26th AEWG Meeting, Reno, Nevada, 2-5 April 1984.

36. Teoh, H.B., Roman, Itzhak, and Ono, K. "Impurity Segregation at Inclusion-Matrix Interfaces and Burst-Type Acoustic Emission of A533B Steel," presented at the 26th AEWG Meeting, Reno, Nevada, 2-5 April 1984.

37. Ono, K. "Acoustic Emission Techniques for Materials Research," Nagoya University, Nagoya Japan, November 1984. (Invited Seminar)

38. Roman, I., and Ono, K., "AE Behavior of Advanced Aluminum Alloy," presented at the Second International AE Conference, Lake Tahoe, Nevada, October, 1985.

39. Ono, K., "Acoustic Emission from Structural Materials," ALCOA Technical Center, New Kensington, 24 June 1985. (Invited)

40. Roman, I., Ono, K., and Kwon, O.Y. "Burst Emission Behavior of Structural Steels," presented at the Second International AE Conference, Lake Tahoe, Nevada, October, 1985.

41. Ohtsu, M., and Ono, K. "Discrimination of Fracture Mechanisms via Pattern Recognition Analysis of AE Signals during Fracture Testing," presented at the Second International AE Conference, Lake Tahoe, Nevada, October, 1985.

42. Ono, K. "Acoustic Emission from Advanced Structural Materials," NKK Technical Center, Kawasaki, 26 June 1986. (Invited Seminar)

43. Ono, K., "Acoustic Emission from Structural Composites," Honda R&D Center, Wako, Japan, 4 July 1986. (Invited Seminar)

44. Ono, K., and de Spain, R. "Characterization of Carbon Fiber Composites using Acousto-Ultrasonic Techniques" SPI CRP International Symposium - 1983, Proceedings of the First International Symposium on AE from Reinforced Plastics, Soc. Plastics, Ind., New York,1983, Session 6, pp. 1-5.

45. Johnson, C., Ono, K., and Chellman, D., "Acoustic Emission Behavior of Whisker Reinforced Aluminum during Fracture," presented at the Second International AE Conference, Lake Tahoe, Nevada, October, 1985.

46. Roman, I., and Ono, K., "Acoustic Emission Characterization of Fracture Mechanisms in Woven Roving Glass-Epoxy Composites," presented at the 27th AEWG Meeting, San Antonio, TX, 4-7 February 1985.

47. Johnson, C.H., Roman, I., and Ono, K., "Progress Report on Acoustic Emission Studies of Composite Materials and Structures," presented at the 27th AEWG Meeting, San Antonio, TX, 4-7 February 1985.

48. Johnson, C., Ono, K., Chellman, D. "A Study of Mechanical Behavior of Metal Matrix Composites Using Acoustic Emission," Proceedings of the Third Japan-U.S. Conference on Composite Materials, in Composites '86: Recent Advanceds in Japan and the United States, K. Kamwata, S. Umekawa and A. Kobayashi, eds, Tokyo, 1986.

49. Ono, K., "Acoustic Emission Behavior of Flawed Unidirectional Carbon Fiber-Epoxy Composites," presented at the 2nd International Symposium on AE from Reinforced Composites, Montreal, July, 1986, Soc. Plastics Industry.

50. Ono, K. "Acoustic Emission from Structural Materials," Nippon Steel Corp. Research Center, Kawasaki, 27 June 1986. (Invited)

51. Ono, K., M. Ohtsu and S. Jensen "Identification of Damages in Unidirectional Carbon

Fiber-Epoxy Composites with Artificial Flaws via Acoustic Emission Techniques," WESTEC '87, March 23-26, 1987, Los Angeles, CA and The Sixth International Conference on Composite Materials, London, England, July 21-25, 1987.

52. Ono, K., J.M. Yang and J.S. Jeng, "Fracture Mechanisms Study of Carbon Fiber Thermoplastic Composites via Acoustic Emission", ASTM Symposium on Fracture Mechanisms on Thermoplastic Composites, Miami, FL, Oct. 17-19, 1987 and ISTFA/87, Los Angeles, CA, Nov. 9-13, 1987.

53. Ono, K. "Identification of Damages in Composites via Acoustic Emission and Acousto-Ultrasonic Techniques, 1987 Winter Meeting of ASME, Boston, MA Dec. 13-18, 1987. (Invited)

Students and Scholars

The following students and postdoctoral scholars received financial support from the contract:

Mr. Albert Avalos, Undergraduate Student (Lab Assistant, Mar. - June, 1986)

Mr. I. Chen, Undergraduate Student (Jan. -June 1985)

Mr. C. Horvath, Undergraduate Student (Jan. -June 1983)

Dr. S.-Y. S. Hsu (Ph.D. completed in Jan. 1981)

Mr. S. Jensen, Undergraduate Student (Lab Assistant, Jan. - June 1985; Mar. 1986 - Sep. 1987)

Mr. Craig Johnson (M.S. completed Dec. 1986)

Mr. E. Kobayashi, unsupported visitor (Sep. 1980 - Aug. 1982).

Dr. M. Man Kwan, (Ph. D. completed in 1983)

Dr. O.Y. Kwon, (Ph.D. completed in March 1988).

Mr. M.Y. Mochiki, unsupported visitor (June 1984 - June 1986)

Mr. D.L. Newell, Graduate Student (Sep. 1982 - Jan. 1983)

Dr. M. Ohtsu, Visiting Assistant Research Engineer (Two months during Oct. - Nov., 1985 and July to August 1986).

Mr. K. Okajima, Graduate Student (M.S. completed Jan. 1981).

Dr. I. Roman, Visiting Research Engineer (July - Aug, 1981; Sep. 1982 - Aug. 1983; Aug. - Oct. 1984; July 1985)

Dr. M. Shibata, Staff Research Engineer (Nov. 1981 - August 1982).

Dr. H.B. Teoh (Ph. D. completed in December 1984).

Mr. Gerry Zamiski (Ph.D. candidate, continuing)

ABSTRACT OF THE DISSERTATION

Acoustic Emission Characterization of Materials
by Digital Waveform Processing and Recognition

by

Oh-Yang Kwon
Doctor of Philosophy in Materials Science and Engineering
University of California, Los Angeles, 1988
Professor Kanji Ono, Chair

Statistical pattern recognition based on the analysis of an individual acoustic emission (AE) signal have been studied for the effective discrimination of AE source mechanisms. An individual AE waveform was analyzed by the use of digital filtering or linear system modeling. It is shown that almost real-time processing and recognition of incoming AE signals can be achieved by utilizing digital computers. With currently limited applicability of fundamental approaches, the present approach can fulfill the need for applications of AE to the characterization of materials and processes.

Two types of digital waveform processing techniques were developed. An envelope-based waveform recognition was for the repetitive magneto-acoustic emission (MAE) and surface Barkhausen (SBN) signals whereas the autoregressive modeling via digital inverse filtering was for transient AE signals. The

inverse filtering with z-transform provided the spectral estimation of transient AE signals. The parameters in the frequency domain constituted a feature set for pattern recognition.

The microstructural variations of A533B steel and the stress states of AISI 1018 steel bars were successfully determined by the envelope-based pattern recognition of MAE signals. SBN waveforms were also useful for microstructural changes but of no use for stress states. Pattern recognition of MAE waveforms determined the radiation damages of reactor vessel steels as well. This can be a new nondestructive evaluation method for nuclear reactor components.

AE monitoring of multi-pass submerged-arc welding was studied by the system modeling-based waveform recognition of transient AE signals. AE signals due to copper-induced hot cracks were clearly isolated from signals due to phase transformations. The recognition power, however, was insufficient to completely overcome the presence of various noise in this noisy process. Although the inverse filtering required an off-line computer running under UNIX, the present study indicates the potential of discriminating AE signals from different sources in real-time. Further improvements may be necessary for practical applications.